Arizona Department of Water Resources
Hydrology Division

ARIZONA DEPARTMENT OF WATER RESOURCES

Santa Cruz Active Management Area 1997-2001 Hydrologic Monitoring Report

December 2001

By

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INTRODUCTION

In 1994, the legislature recognized the significant differences between the Upper Santa Cruz River Basin and the other groundwater basins in the Tucson Active Management Area by establishing the Santa Cruz Active Management Area (Santa Cruz AMA or SCAMA) (fig. 1). The legislation specifically noted the international nature of water management issues and that the basin hydrology required coordinated management between the surface water and groundwater.

In order to address the unique hydrologic nature of the Santa Cruz AMA, the legislature gave them a dual goal. The first component of the management goal is to preserve safe-yield conditions on an AMA-wide basis. The second component is to prevent the occurrence of long-term declines in local water tables.

In 1996 the Arizona Department of Water Resources (ADWR) developed a groundwater and surface water-monitoring program for SCAMA. The purpose of the program is to provide the hydrologic data required to determine whether SCAMA is maintaining its long-term “safe-yield” management goal. The monitoring program also provides hydrologic information, which is being utilized in the construction and calibration of a regional groundwater flow computer model.

The original monitoring program consisted of quarterly measurement of surface water flow, annual groundwater measurements, and collection of other related hydrologic data. In the fall of 1997 the monitoring program was refined to include the monthly measurement of groundwater levels and surface water flow. A staff member was hired under a three-year Environmental Protection Agency (EPA) grant specifically to collect and analyze hydrologic data in Santa Cruz AMA. The analysis was to include the characterization of the groundwater surface water interaction and the seasonal nature of hydrologic process of the basin.

Department personnel have collected over 1,000 groundwater levels during the period of October 1997 through June 2001 in the AMA and the Upper Santa Cruz Sub-basin in Sonora, Mexico. The Department has also installed pressure transducers within the AMA to record continuous groundwater level changes. Hundreds of baseflow measurements have been recorded along sections of the Santa Cruz River both above and below the effluent discharge point at the Nogales International Wastewater Treatment Plant. The baseflow measurements compliment the continuous surface water flow measurements that are recorded by the United States Geological Survey (USGS) near Nogales and Tubac at surface water monitoring sites S11 and S4, respectively. In addition to the groundwater and surface water measurements, the Department has conducted micro-gravity surveys in portions of the AMA to provide estimates of the volumetric groundwater storage change, specific yield and depth to bedrock.

The purpose of this report is to present the data gathered to date in the Santa Cruz AMA in support of the management goal and groundwater modeling effort. This report presents groundwater and surface water monitoring data, USGS stream gaging data, effluent data, gravity studies, historical water use and water quality data for three distinctive stream reaches of the Santa Cruz River. The three reaches that are discussed are from upstream to downstream (south to north): 1) Santa Cruz River from San Lazaro, Mexico to the International Border; 2) the International Border to the Nogales International Wastewater Treatment Plant; and 3) the treatment plant to the northern AMA boundary near Amado. This report is not intended to provide a detailed analysis of the data. A detailed discussion of the data will be included in a future report that will discuss the results of the groundwater model

Terms Used in this Report

The alluvium in the Upper Santa Cruz Basin varies in thickness, extent, compaction, cementation, and grain size and is commonly referred to as the Younger Alluvium and Older Alluvium. The Younger Alluvium (YAl) refers to the younger surficial deposits of Holocene and Pleistocene age (Drewes, 1980). It is described as mostly light gray, unconsolidated to poorly consolidated gravel, sand, silt, clay, occasional boulders, and some caliche (Drewes, 1980 and Coates and Halpenny, 1954). The Older Alluvium (OAl) is of Quaternary and Tertiary age and is described as thicker, more widespread, compacted and cemented and, in general, consists of more fine-grained materials (except near the mountains) than the YAl. Overall, it is generally light-pinkish gray, weakly indurated, and with poorly rounded clasts. In some locations it is locally well indurated.

For the purposes of this report, surface water refers to water that was measured within the river channel and groundwater refers to water measured in wells.

The authors would like to emphasize that any references to younger or older alluvium, surface water, and groundwater are in no way legal determinations and should not be interpreted as such. The terms are commonly used terms in other reports and have been chosen for ease of reference.

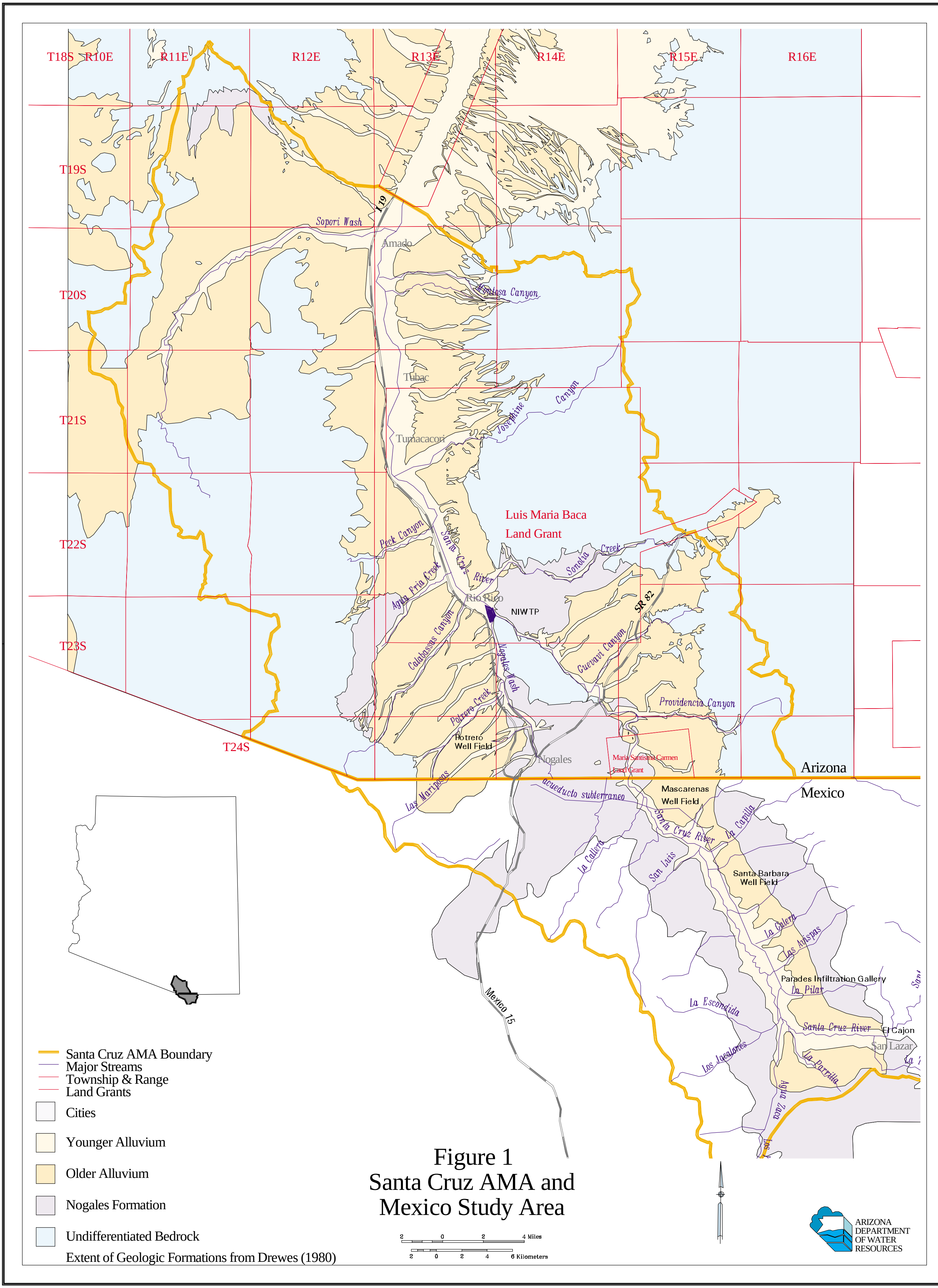

Figure 1
Santa Cruz AMA and
Mexico Study Area

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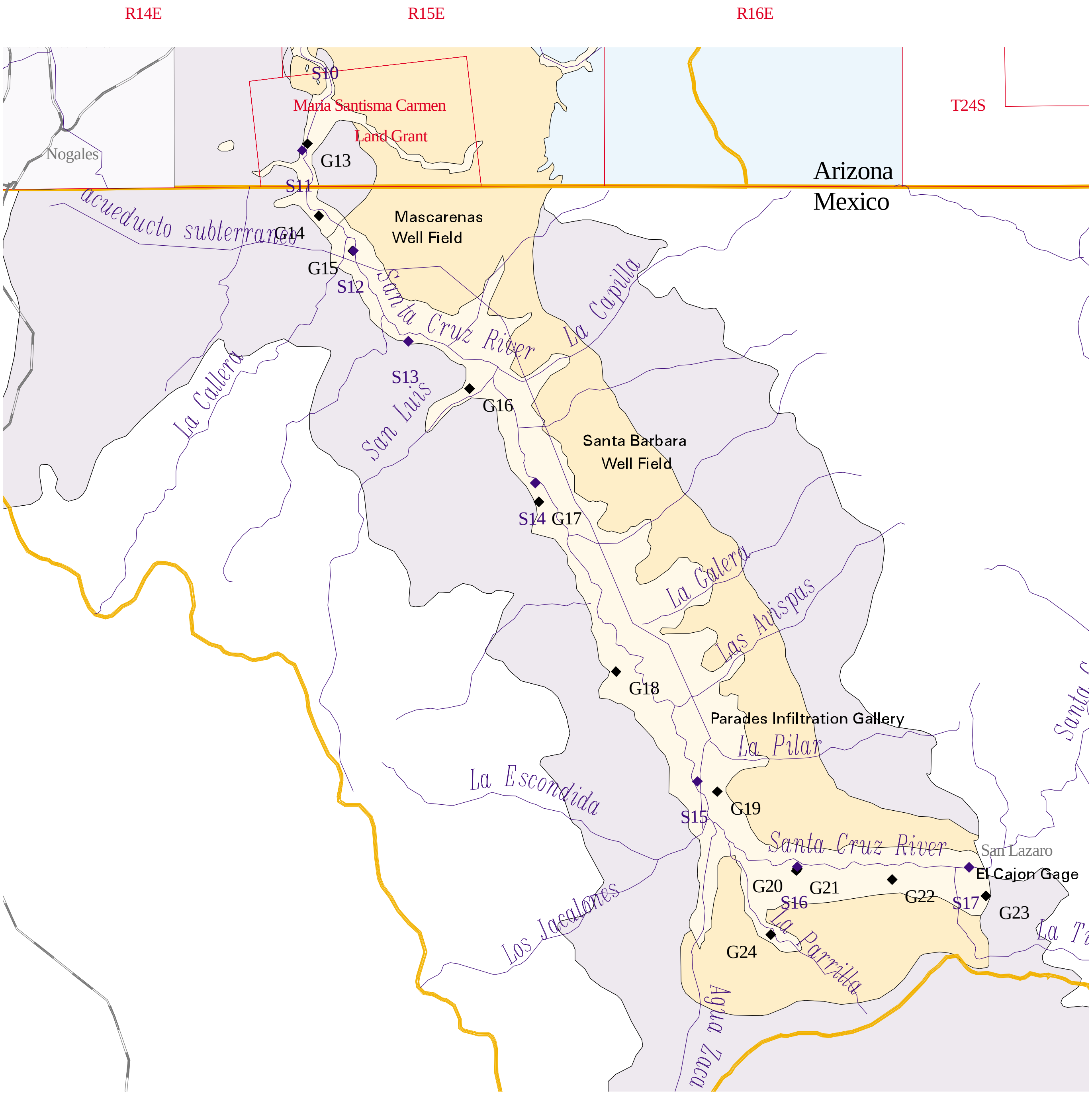
GROUNDWATER LEVEL MONITORING

On the average twelve wells within the Santa Cruz River Younger Alluvium (YAl) are currently measured for depth to water from the International Border to Elephant Head Bridge near Amado in the northern part of the AMA. Most of these wells have been measured on a near-monthly basis since the fall of 1997. Currently, water levels from six wells located upstream of the Nogales International Wastewater Treatment Plant (NIWTP) and six wells located downstream of the NIWTP (i.e., the effluent-dominated portion of the Santa Cruz River) are monitored. The locations of the monitor wells were selected based on their proximity to surface water measuring sites and most were located away from nearby pumping interference sources.

The Department has also measured groundwater levels in wells that primarily produce water from the OAl on a less frequent basis because water level changes typically occur at slower rates than in the YAl. All measured groundwater levels are available in the Department's Groundwater Site Inventory (GWSI) database (GWSI, 2001). In February 2000, the Department, in cooperation with the University of Sonora, began exchanging water level measurement data in the YAl in Sonora, Mexico from approximately San Lazaro, near El Cajon, to near the International Border. Table 1 lists the groundwater monitoring sites and they are shown on figures 3 through 5.

Figure 2. Department personnel measuring groundwater levels in a well drilled into the older alluvium south of Potrero wellfield (G12).



Santa Cruz Watershed Boundary
Major Streams
Township & Range
Ground Water Measurement Sites
Surface Water Measurement Sites
Younger Alluvium
Older Alluvium
Nogales Formation
Undifferentiated Bedrock
Extent of Geologic Formations from Drewes (1980)

Figure 3
Upper Santa Cruz Basin
Sonora, Mexico
Showing Surface Water and
Groundwater Measurement Sites

2 0 2 4 Miles

2 0 2 4 6 Kilometers

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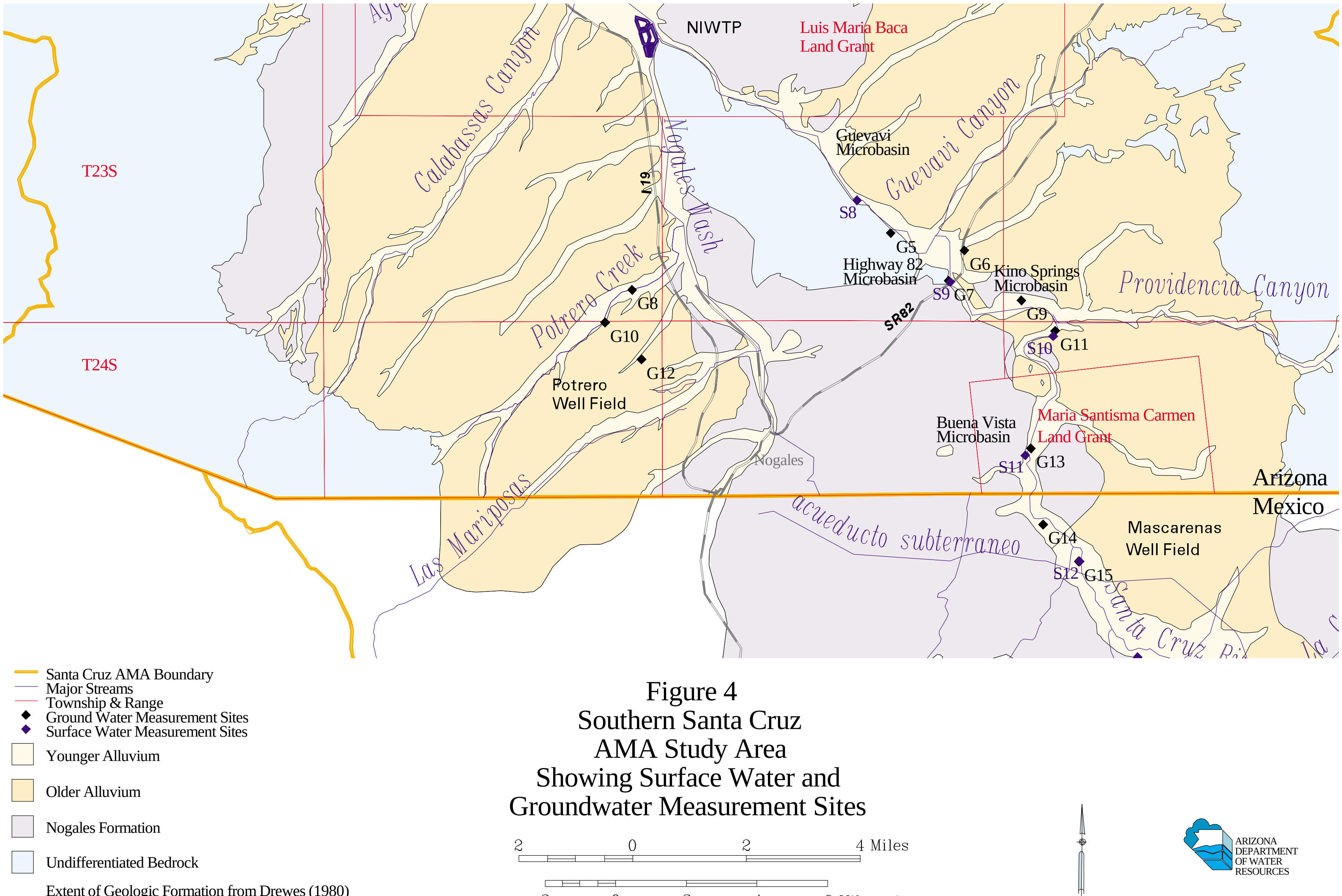

Figure 4
Southern Santa Cruz
AMA Study Area
Showing Surface Water and
Groundwater Measurement Sites

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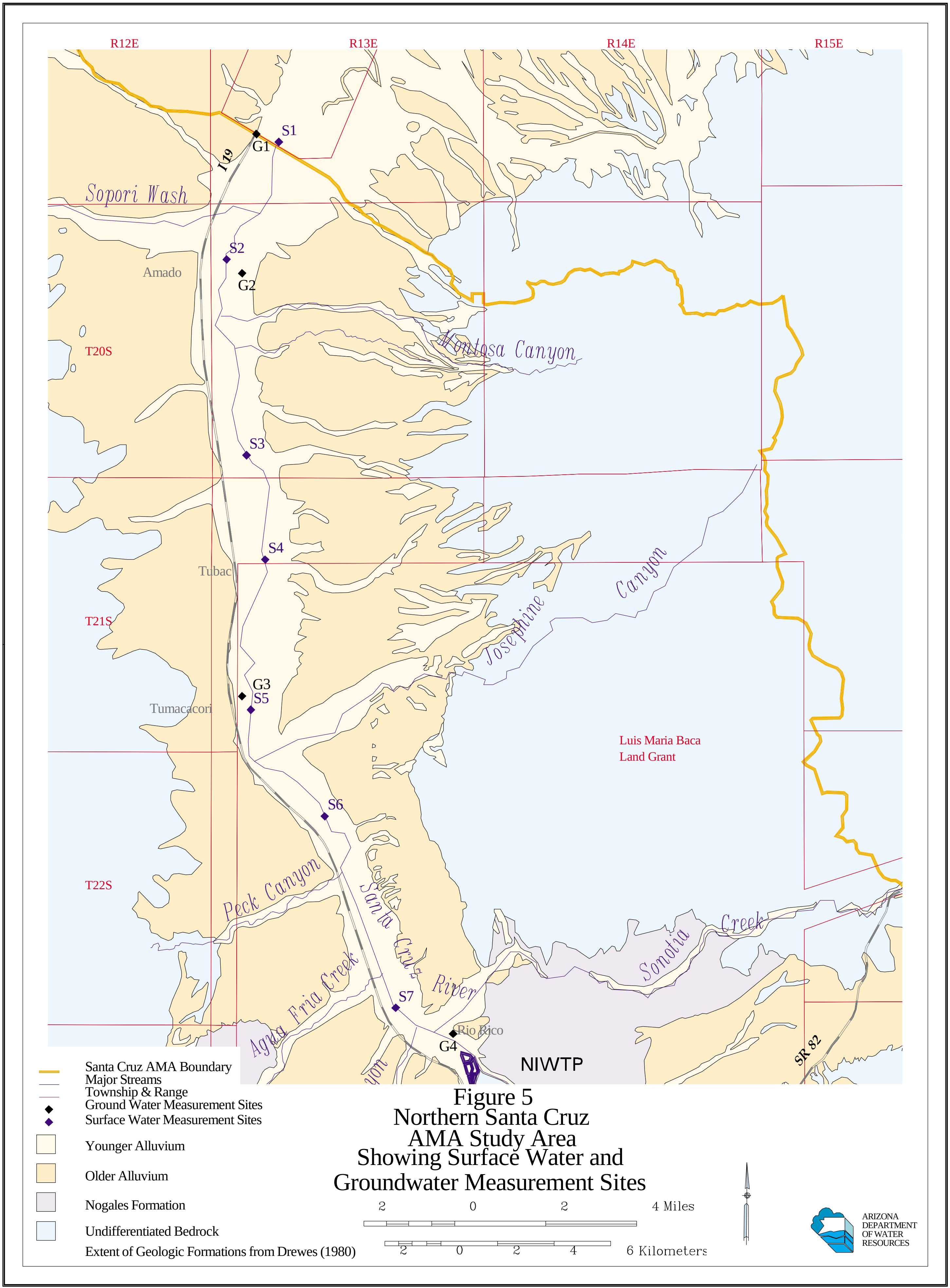


Figure 5
Northern Santa Cruz
AMA Study Area
Showing Surface Water and
Groundwater Measurement Sites

Table 1. Groundwater measurement sites

Map Site	*Well Location Description*	*ADWR Registration Number**	*Cadastral Location*	*UTM east*	*UTM north*	*Latitude*	*Longitude*
						Deg Min Sec	Deg Min Sec
G1	Elephant Head	55-623122	(D-19-13)29bbc	495869	3512355		
G2	Amado	55-617275	(D-20-13)07acd	495367	3507429		
G3	Santa Gertrudis nr Tumacacori		(D-21-13)30dca	495361	3492467		
G4	Rio Rico		(D-23-13)bbd unsurveyed	205824	3480521		
G5	Santa Fe	55-619646	(D-23-14)27add	510325	347353		
G6	Adrians Well		(D-23-14)25cdb	512412	3473263		
G7	Gallery	55-603439	(D-23-14)36bcb1	511964	3472400		
G8	Meadow Hills	55-506340	(D-23-13)36bdd	503011	3472147		
G9	CIT	55-625359	(D-23-15)31cac	514025	3471849		
G10	Potrero Well	55-619171	(D-24-13)01bbb	502245	2471223		
G11	Kino Springs		(D-24-13)06aad	514977	3470988		
G12	Potrero South	55-571751	(D-24-13)01dbd	503276	3470177		
G13	Buena Vista		(D-24-15)18bad unsurveyed	514295	3467662		
G14	Helicopter Well					31 19 32.3	110 50 45.5
G15	Mascarenas					31 18 57.6	110 50 07.7
G16	La Laguna					31 16 44.3	110 47 55.9
G17	Santa Barbara					31 14 54.4	110 46 38.3
G18	Los Picos					31 12 09.1	110 45 10.5
G19	Paredes Solar					31 10 12.3	110 43 17.3
G20	River Bend AG					31 08 59	110 41 47
G21	River Bend WM					31 08 55	110 41 48
G22	El Silo					31 08 50.2	110 40 18
G23	San Lazaro					31 08 30	110 38 14
G24	OAl Well					31 07 52.9	110 42 16.9

*** Registration numbers only reported where verified by ADWR personnel.**

Groundwater Monitoring
San Lazaro, Sonora to International Border
Mexico Reach

Eleven wells are currently measured on a quarterly-basis from San Lazaro, Sonora, Mexico to near the International Border (fig. 3). Table 2 contains a summary of groundwater level measurements. Static groundwater level change has varied from less than one foot near San Lazaro (G23), to almost 20 feet near Paredes Ranch (G19).

Table 2. Depth to water measurements with respect to land surface (feet) in Sonora, Mexico.

	G14	*G15*	*G16*	*G17*	*G18*	*G19*	*G20*	*G21*	*G22*	*G23*	*G24*
2/24/2000	9.4	10.5	10.9	7.5	16.4	40.4	9.5	12.6	9.4		77.7
6/15/2000	13.5	180.7p	12.3	13.4	17.2	50.5	14.6	17.2	12.0	12.2	81.7
9/28/2000	15.9	188.8p	10.9	13.8	18.2	40.6	9.0	12.7	12.6	12.5	79.1
12/20/2000	7.2	9.6	5.8p	5.5	12.7	31.7p	8.5	11.9	10.4	12.2	78.5
3/30/2001	7.4	9.7	5.9	6.1	15.8	30.7	9.5	12.1	9.9	12.3	79.0
6/22/2001	9.2		10.2	10.0	17.6	31.2	12.8	15.7	12.3	12.9	79.1

p indicates dynamic pumping level.
All data rounded to the nearest tenth of a foot.

Groundwater Monitoring
International Border to NIWTP
Microbasin Reach

A series of four sub-basins referred to as microbasins, extend along the Santa Cruz River from the International Border to the NIWTP (Halpenny, 1963, Putman, 1983,and Halpenny 1991). These microbasins are as much as 100 feet deep and are enveloped and floored by low-permeability formations. They are separated from each other by outcrops of Nogales Formation on the east side which, associated with shallow bedrock at each location, constrains hydraulic conductivity between the basins and makes them each semi-separate. Four microbasins have been identified: 1) Buena Vista, 2) Kino Springs, 3) Highway 82, and 4) Guevavi. Figure 4 shows the locations of the individual basins.

The magnitude of groundwater level change in this reach is affected by many factors including aquifer size and available storage capacity, the aquifer characteristics, the magnitude and duration of surface flow, the frequency and magnitude of imposed stresses (e.g., pumping, evapotranspiration, and recharge from river and tributaries), bank storage, streambed infiltration and seasonal climatic conditions.

Groundwater levels in the YAl are greatly influenced by surface water flow. Because the effective storage volume in each of the microbasins is relatively small, groundwater levels are very responsive to stresses including pumping and natural surface water recharge. For example, following the October 2000 flood event, it took less than one month for the aquifer to fully recharge in the microbasin areas (figs. 6 and 7). In contrast, it took approximately six months before groundwater levels reached a maximum level near Elephant Head Bridge and Amado from the same flood and recharge event because of the much greater overall groundwater storage volume in the aquifer in that area (fig. 8).

The magnitude of groundwater level fluctuations in the individual microbasins varies significantly. However, seasonal groundwater level changes are generally less than 10 feet in the Buena Vista and Guevavi microbasins because pumping stresses are currently minimal. In the Kino Springs and Highway 82 microbasins, groundwater levels have fluctuated more than 50 feet in a season at monitor site G7, (D-23-14) 36bcb1, due to municipal pumping demand.

Figure 6. Groundwater levels and surface water flow (provisional data) in the microbasins. (Gaps in plotted data indicate no flow conditions.)

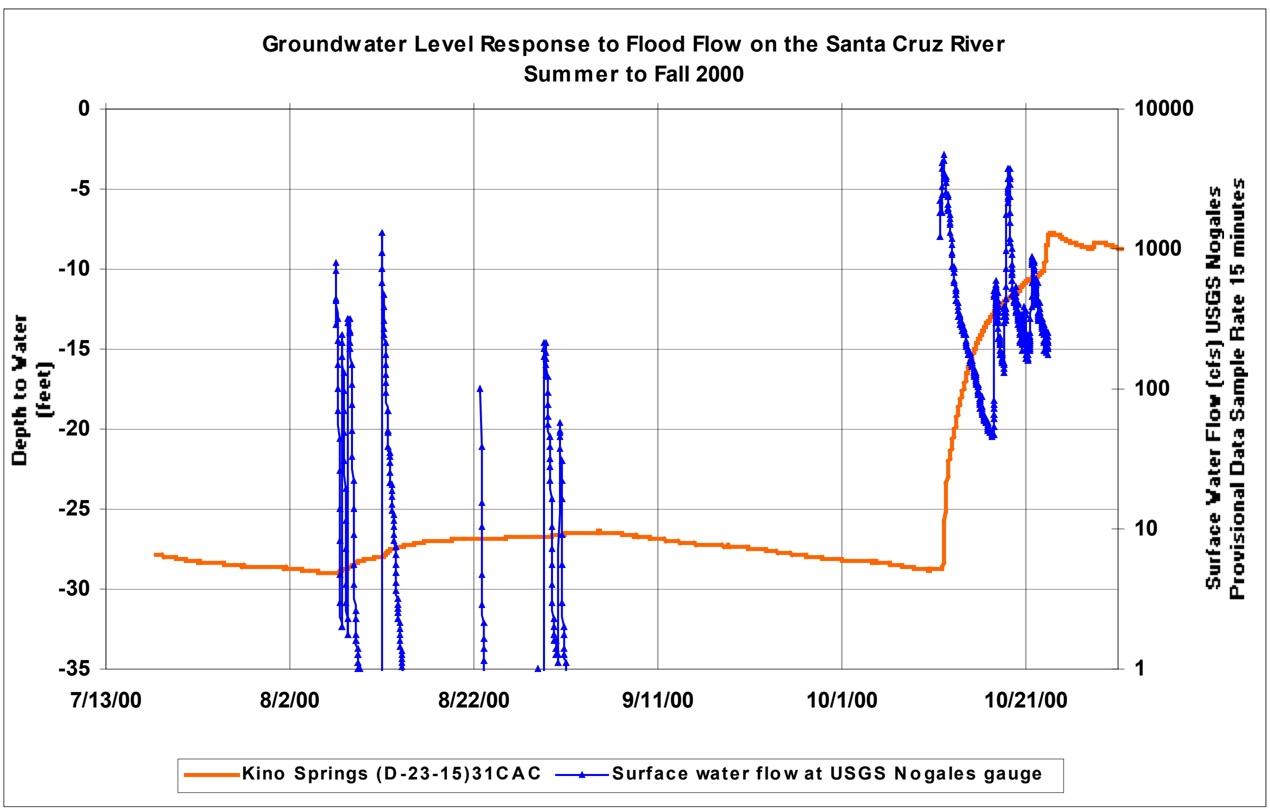
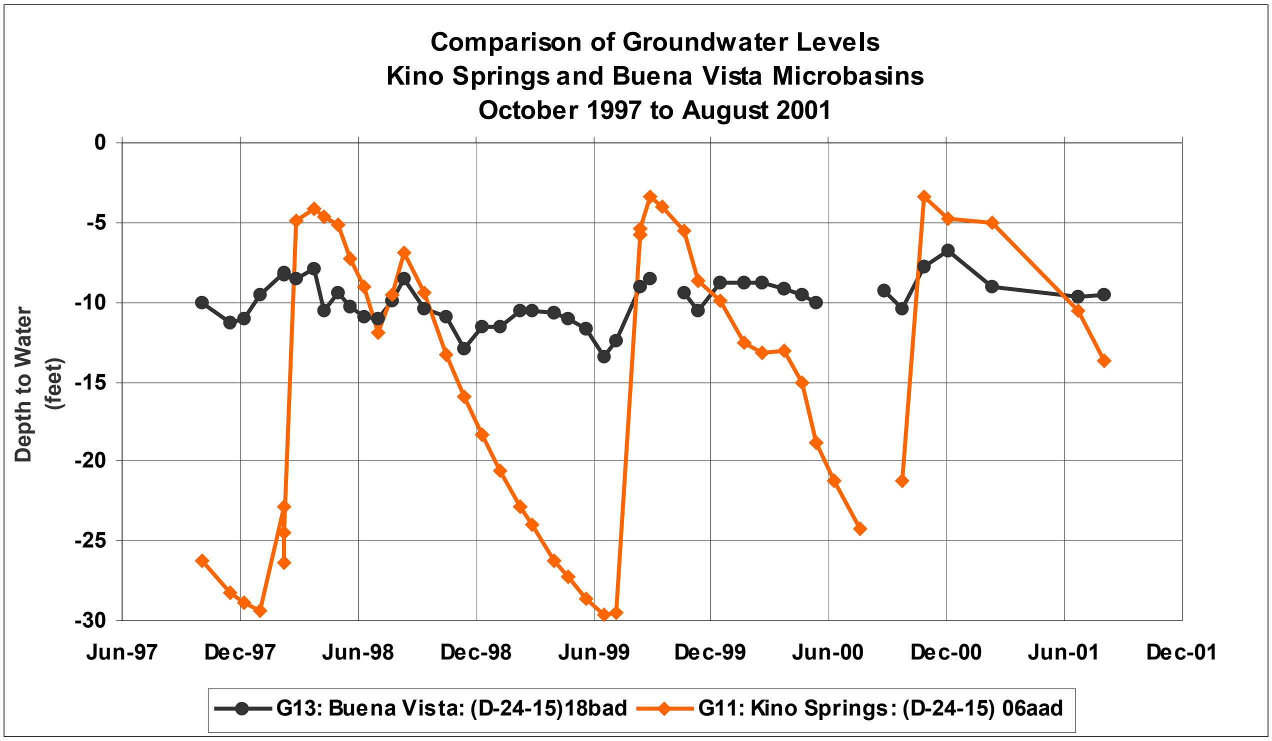


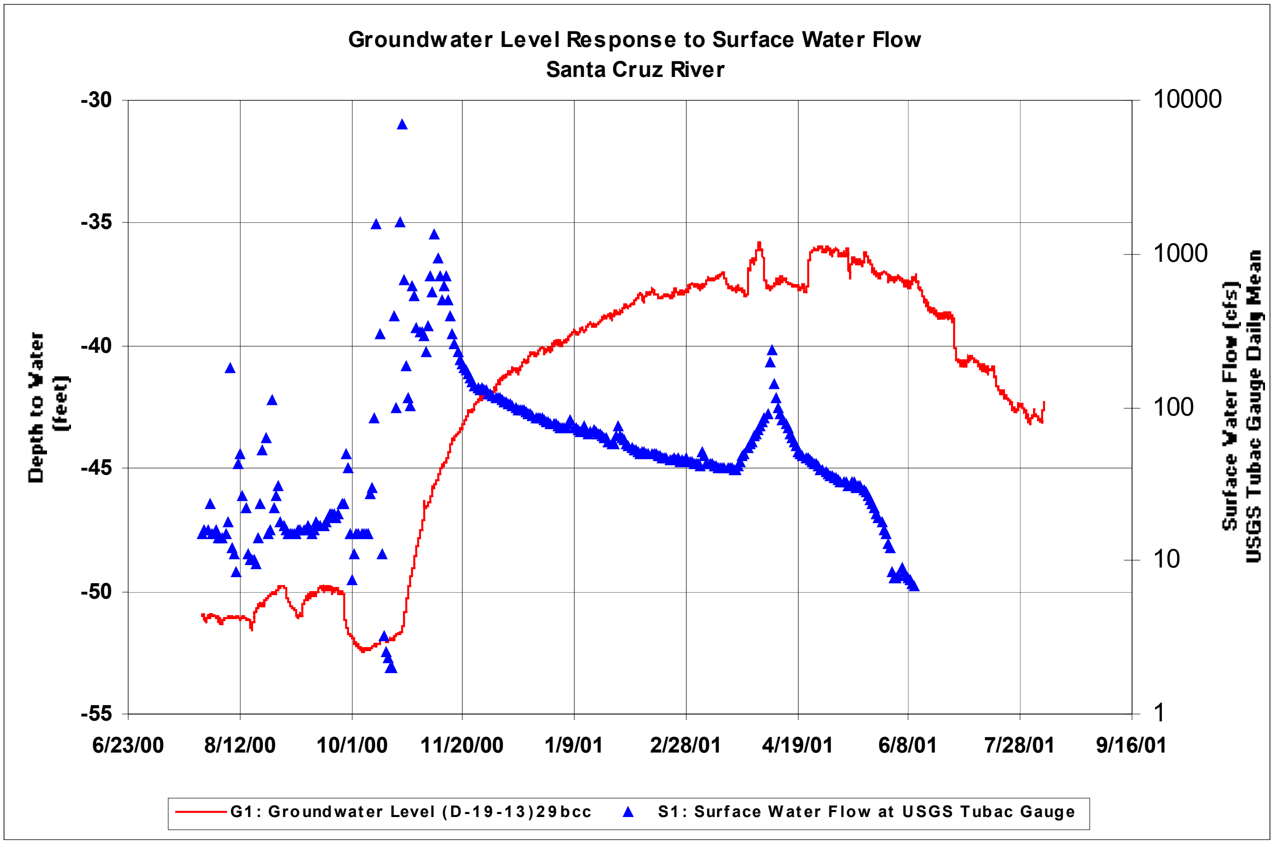
Figure 7. Groundwater levels in the Buena Vista and Kino Springs microbasins.



Groundwater Monitoring
NIWTP to Elephant Head Bridge
Effluent-Dominated Reach

As expected, groundwater level changes in the YAl show a strong connection with surface water flow in the reach of the Santa Cruz River between the Nogales International Wastewater Treatment Plant and the northern boundary of the AMA (near Elephant Head Bridge and Amado). In general, groundwater levels along the perennial stretch of the Santa Cruz River, from approximately the NIWTP to Tubac, are stabilized by the continuous release and recharge of effluent from the NIWTP along the Santa Cruz River. Over the course of the program, groundwater levels in the YAl varied seasonally from only a few feet below land surface (the magnitude of oscillation only a few feet; depth to water approximately 12 feet) near Tumacacori to greater than 15 feet near Rio Rico (G4) and Amado (fig. 8, figs. 14-16). With the exception of the Rio Rico location at (D-23-13) 30dca, groundwater levels adjacent to the perennial stretch of the river typically fluctuate less than six feet. However, the magnitude of seasonal groundwater level changes adjacent to intermittent stretches of the river (approximately Tubac to Elephant Head Bridge) are more variable and have fluctuated more than 15 feet.

Figure 8. Groundwater level and surface water flow (provisional data) in northern portion of Santa Cruz AMA.



Transducer Locations

Pressure transducers have been installed to provide a continuous water level record in critical areas where water levels change rapidly in response to groundwater pumping, surface water flows and riparian demands. The Department currently has four pressure transducers installed in the productive zone of the YAl near Kino Springs (G9), Nogales pump house or Gallery (G7), Rio Rico (G4) and near Elephant Head Bridge (G1). In addition, the Department has equipped wells in the vicinity of Nogales' Potrero well field with transducers. Table 3 contains a list of the transducer locations and related data.

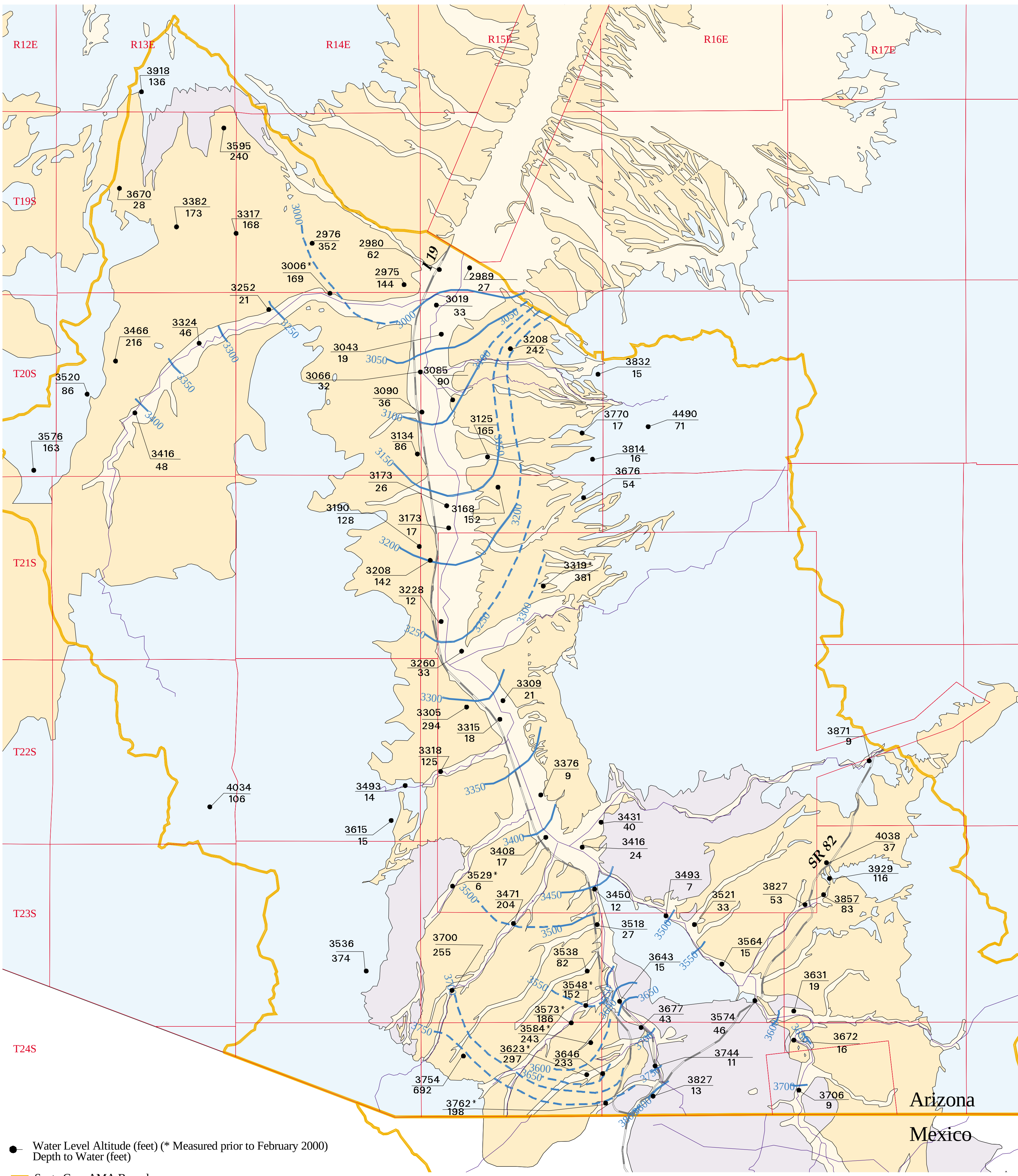
Table 3. Location of pressure transducers in the Santa Cruz AMA

Location	*Local ID*	*Well Owner*	*Approximate Depth-to-water Range (feet)*	*Period of Record*
Potrero Canyon (G12)	(D-24-13)01bbb	City of Nogales	175-190	4/2/98 – 5/27/98
Meadow Hills (G8)	(D-23-13)36bdd	City of Nogales	145-160	6/16/98 – present (intermittent record)
Potrero South (G10)	(D-24-13)01dbd	ADWR/SCAMA	240-245	7/14/99 – present
Kino Springs (G9)	(D-23-15)31cac	City of Nogales	10-40	7/18/00 – present
Rio Rico (G4)	(D-23-13)01bbd	Rio Rico Properties	10-30	7/18/00 – present
Highway 82 Bridge (G7)	(D-23-14)36bcb1	City of Nogales	10-65	7/19/00 – present
Elephant Head Bridge (G1)	(D-19-13)29bcc	Green Valley Water Co.	35-50	7/26/00 – present

Figure 9. Downloading data from pressure transducer at a well near Elephant Head Bridge (G1).

Santa Cruz AMA Groundwater Level Map

Annually, Department personnel collect a comprehensive set of water level measurements and gather a large volume of data within the Santa Cruz AMA in order to characterize groundwater conditions. During February and March of 2000, approximately 170 wells were measured. Most of the groundwater level measurements recorded over this time period were used to generate the water level contour map shown in figure 10. The majority of groundwater levels were measured in relatively shallow wells tapping unconfined aquifers (the younger alluvium) associated with surface water sources including the Santa Cruz River and its tributaries (see the solid-blue contour lines in figure 10). The map also includes a composite of groundwater levels measured in deeper wells associated with the regional aquifer (the older alluvium). Groundwater level contours for the regional aquifer have been inferred because there may be vertical hydraulic gradients associated with these areas and the few wells that exist penetrate the aquifer at different depths (see the dashed-blue contour lines in figure 10).



Water Level Altitude (feet) (* Measured prior to February 2000)
Depth to Water (feet)

Santa Cruz AMA Boundary

Major Streams

Township & Range

Water Level Contour (feet)- Shows Approximate Altitude of the Water Level. Datum is Mean Sea Level

Water Level Contour - Shows Approximate Altitude of Hydraulic Head In Regional Aquifer. Datum is Mean Sea Level

Younger Alluvium

Older Alluvium

Nogales Formation

Undifferentiated Bedrock

Extent of Geologic Formations from Drewes (1980)

Figure 10
Depth to Water and Altitude of the Water Level, February / March 2000

2 0 2 4 Miles

2 0 2 4 6 Kilometers

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SURFACE WATER FLOW MEASUREMENTS

The surface water flow rate is measured monthly at seven sites by ADWR along the effluent-dominated portion of the Santa Cruz River, and four sites in the microbasin area when flow exists. In addition, the University of Sonora conducts quarterly measurements at six sites in Mexico from near San Lazaro to approximately the International Border. It should be noted that these are single measurements, and therefore only provide a snapshot of flow conditions occurring at that particular time. These specific measurements cannot be used to calculate or infer a volume of water being recharged at a given location. Calculating recharge for a specific reach involves analyzing many interdependent factors such as evapotranspiration rates, open-channel evaporation rates, pumping stresses, antecedent stream channel and bank storage conditions and effluent discharges (if any) which may vary complexly throughout the day. Thus, assessment of local and regional water budgets which require estimates of recharge, pumpage, evapotranspiration, etc. are not provided in this report, but will be provided in a separate report when the calibrated computer groundwater model is complete.

Table 4. Surface water measurement sites.

Map Site	*Location Name*	*Latitude Deg Min Sec*	*Longitude Deg Min Sec*
S1	Elephant Head	31 44 45	111 02 07
S2	Amado	31 42 30	111 03 17
S3	Chavez Siding	31 38 45	111 02 50
S4	Tubac	31 36 45	111 02 25
S5	Santa Gertrudis near Tumacacori	31 33 43	111 03 42
S6	Palo Parado	31 31 50	111 01 05
S7	Rio Rico	31 28 10	110 59 30
S8	Guevavi Narrows	31 24 30	110 54 05
S9	Highway 82	31 23 15	110 52 25
S10	Kino Springs Bridge	31 22 25	110 50 35
S11	Buena Vista	31 20 40	110 51 05
S12	Macrenas	31 18 57.6	110 50 07.7
S13	River Park	31 17 30	110 49 05
S14	Santa Barbara	31 15 13	110 46 22.5
S15	Infiltration Galeria	31 08 50.2	110 40 18
S16	River Bend	31 08 59.1	110 41 47
S17	San Lazaro	31 08 30	110 38 14

Surface Water Monitoring
San Lazaro, Sonora to International Border
Mexico

Surface water flow between San Lazaro and the International Border is mostly intermittent, however, surface water flow has been consistently observed during field activities at the Parque (S13) due to a bedrock constriction in the riverbed at that location. The existence of the infiltration gallery along the Santa Cruz River YAl near Parades has a significant impact on local surface water flow rates (baseflow).

Table 5. Surface water flow (baseflow) measurements Santa Cruz River Sonora reach (cfs)

	Mascarenas	*Parque*	*Santa Barbara*	*Galeria*	*River Bend*	*San Lazaro*
	S12	***S13***	***S14***	*S15*	***S16***	***S17***
2/24/00	0	0.50	0	0	0	
6/15/00		0.30e				
9/28/00		2.00e			3.30	12.60
12/08/00		46.58	49.06		47.96	42.25
3/30/01		20.50	9.65	1.00e	5.00 e	23.50
6/27/01	0	3.24	0	0	0	~4.00e

e indicates estimated surface water.

Surface Water Monitoring
International Border to NIWTP
Microbasins

The Santa Cruz River between the International Border and the Nogales International Wastewater Treatment Plant (NIWTP) is intermittent and surface water flows are dependent upon many factors. The magnitude and existence of baseflow (or recessional flood flow) is directly related to the available storage capacity within each microbasins. For example, during the 1998 El Nino event, intense precipitation and subsequent high level run-off occurred. High infiltration rates of surface flow were observed and recorded along stretches where groundwater levels were relatively deep and storage space was available for recharge. Conversely, low infiltration rates have been observed when the groundwater microbasin(s) are at, or when near, full capacity (table 6, fig. 6). The microbasins thus act as underground storage reservoirs and can sustain groundwater discharge as baseflow along constricted downgradient areas such as Guevavi Narrows, site S8, for many months following a flood event. It has also been observed that when depth to water is less than 20 feet below land surface at site G5, Santa Fe Well (D-23-14)27add, groundwater discharge as surface water flow is observed down gradient at Guevavi Narrows. During the absence of surface water recharge conditions, groundwater pumpage and evapotranspiration, thus reducing and eventually eliminating baseflow along intermittent reaches deplete groundwater.

Figure 11. Santa Cruz River in the Highway 82 microbasin near Santa Fe Ranch facing north: November 2000 (left) and June 2001 (right) (see site G5).

The response of surface water flow and groundwater recharge to flood events can be complex. For example, infrequent, short duration flow events exceeding 1,000 cfs may induce little groundwater recharge and may have minimal associated recessional baseflow (fig. 6-August). However, records show that frequent flooding events such as those seen during the 1999 monsoons, or extremely large flood events having significant recessional flow components such as October 2000, induce significant groundwater recharge and may sustain recessional baseflow for months.

Table 6. Surface water flow (baseflow or recessional flood flow) measurements in the Santa Cruz River microbasins (cfs)

	Buena Vista	***Kino Springs Bridge***	***Hyw82 Bridge***	***Guevavi Narrows***
Date	**S11**	**S10**	**S9**	**S8**
10/08/97-01/05/98	0	0	0	0
02/13/98	36.9	18.6	5.4	0
03/05/98	23.5	23.4	1.1	0
04/01/98	186.1			124.6
04/15/98	15.9	12.8	8.6	0
05/06/98	1	0	0	1.0
05/27/98	0	0	0	1.0
06/15/98	0	0	0	1.0
07/07/98	0	0	0	1.0
07/29/98	0	0	0	1.0
09/16/98-07/13/99	0	0	0	0
08/17/99	55.4	55.4	18.6	0
09/21/99	28.8		23.4	2.7

All data rounded to the nearest .1 cfs.

NIWTP to Elephant Head Bridge
Effluent-Dominated Reach

The Santa Cruz River reach between the NIWTP (near Rio Rico) and Tubac is essentially perennial. Effluent discharged from the NIWTP comprises a significant component of the surface water flow downstream (University of Arizona, 1996). However, records of seasonal baseflow show that the surface water flow rate between Rio Rico and Santa Gertrudis generally increases inferring that the adjacent regional aquifer and stream tributaries, including Sonoita Creek, Agua Fria, Peck and Josephine Canyons contribute significant amounts of water to the hydrologic system. Figures 13 and 14 show how the magnitude of baseflow varies seasonally and with increasing distance downstream from the NIWTP. The error bars on these figures represent the standard deviation of the measurements.

Figure 12. Department personnel measuring surface water flow in the Santa Cruz River near Tumacacori.

Figure 13. Comparison of seasonal baseflow as a function of distance from the NIWTP.

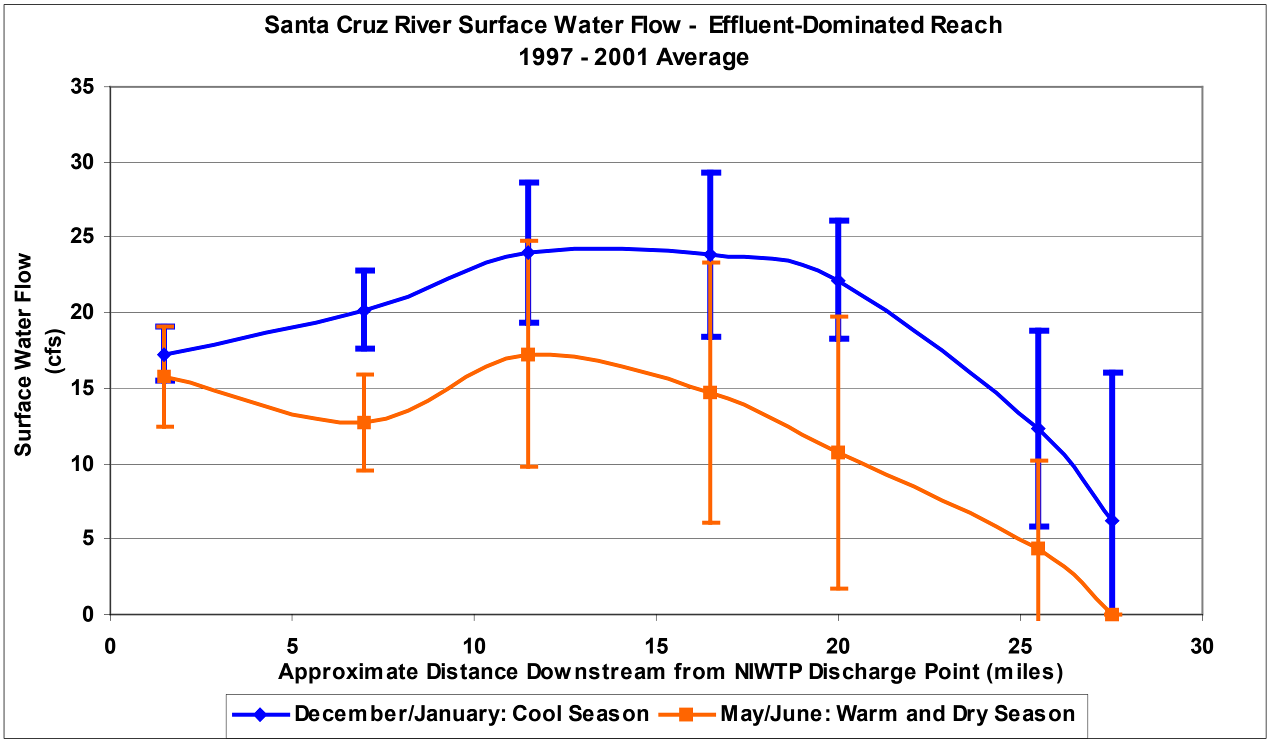


Figure 14. Comparison of seasonal baseflow at Rio Rico, Santa Gertrudis and Elephant Head Bridge.

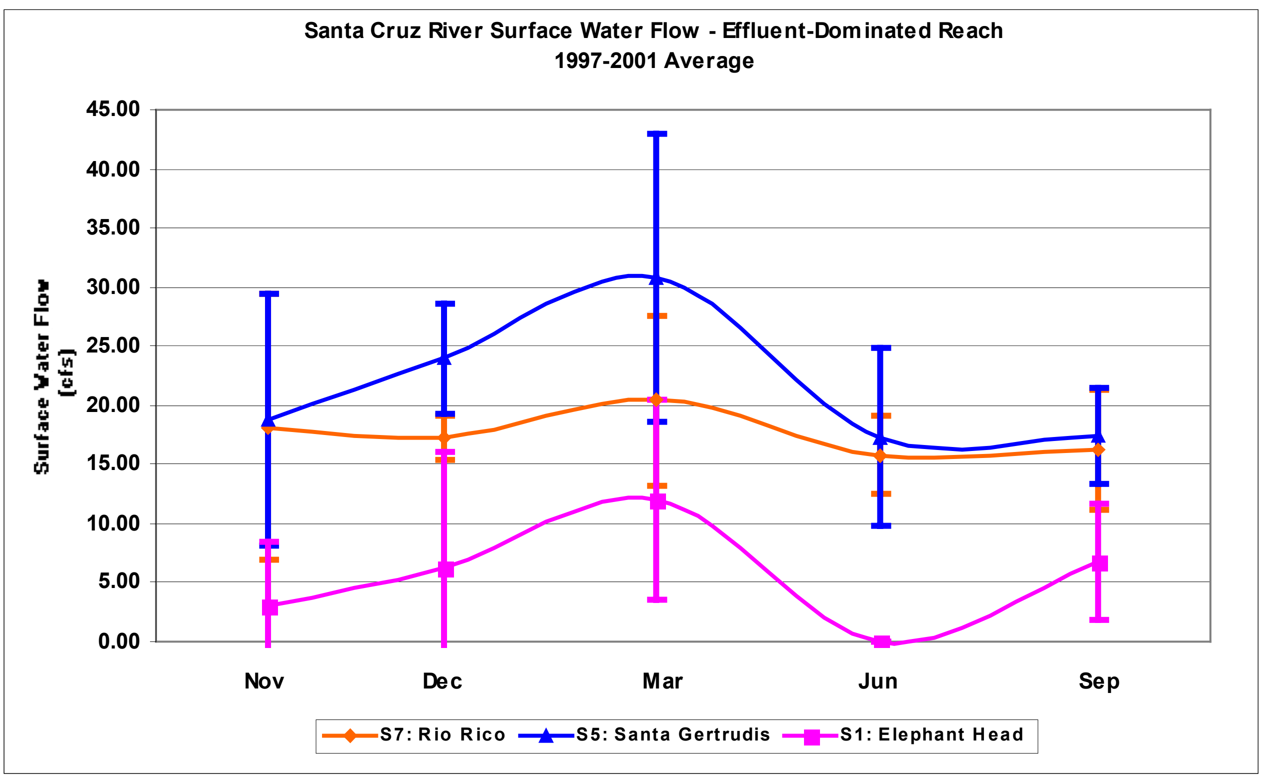


Table 7. Surface water flow (baseflow) measurements in the Santa Cruz River effluent-dominated area (cfs).

	Rio Rico	***Palo Parado***	***Santa Gertrudis***	***Tubac***	***Chavez Siding***	***Amado***	***Elephant Head***
	S7	***S6***	***S5***	***S4***	***S3***	***S2***	***S1***
10/08/97	10.17		6.70	3.00	0.21	0	0
12/12/97	14.45			16.14		4.41	
01/07/98	18.12		18.63	20.73	16.38	6.82	
02/14/98	21.59		28.79	29.36	24.83	11.52	
04/15/98			35.04		35.25	22.93	
05/07/98	19.65		31.73	31.28	28.37	16.74	
05/28/98	16.30			19.86	15.93	4.47	
06/17/98	18.62		17.45	13.84	11.99	1.75	
07/09/98	8.47		16.07	16.43	12.26	3.47	
07/30/98	18.64		15.63	17.14	6.02	0	
09/17/98		19.02	23.03	21.35	19.64	9.05	
11/19/98		19.62	23.07	24.51	21.93	10.59	
12/16/98	16.69	17.38		25.92	24.82	14.96	
01/14/99	18.00	22.26	26.24	29.76	24.07	15.97	
03/02/99	21.25			21.41	20.65	13.8	8.75
04/07/99	14.41	19.33	23.81	22.34	19.98	12.98	7.55
04/30/99	15.08	16.67	18.85	17.76		7.00	4.03
05/26/99	12.09	15.09		9.74	7.21	1.74	0
06/24/99	12.60	8.77	11.15	6.43	3.94	0	0
07/15/99						10.00	10.00
08/18/99	18.04		16.63		12.16	4.72	0
09/22/99	27.76	22.84	26.22	24.32	20.16	11.37	
10/27/99	26.15	25.62	26.72	28.72	26.49	20.38	9.35
01/26/00	19.09	20.98	26.99	26.99	23.48	19.75	17.62
03/29/00	17.05	17.75	21.69	21.81			13.16
04/26/00	17.97	19.56	20.88	19.46			8.36
05/17/00	16.77	15.35	16.10	14.19		5.72	
06/14/00	11.49	9.92	11.61	7.72	4.71		
07/26/00	20.36	16.36	16.60	16.36	15.22		9.11
08/30/00	20.55	22.88	22.56	17.70			11.60
09/27/00							3.31
02/12/01	35.56		51.60		52.75	42.86	29.94
03/29/01		41.88	45.73		37.21	24.91	12.57
06/27/01	18.8	14.60	15.60		3.20	0	0
08/07/01	20.60	16.90	~12.00		<10.00	0	0

The river is effectively perennial and usually gaining at Santa Gertrudis (S5) near Tumacacori. Groundwater level changes of approximately one foot have correlated to changes in baseflow of about 10 cfs (fig. 15). However, downstream near Amado where the river is intermittent and typically losing, the surface water flow rate can be quite variable (fig. 16). Table 5 contains a summary of the baseflow measurements along the effluent-dominated reach of the Santa Cruz River. It should be noted that because the volume of effluent discharged and evapotranspiration demand varies diurnally, surface water measurements were generally recorded at consistent times at each location.

Figure 15. Comparison of depth to water and baseflow: Santa Cruz River effluent–dominated reach near Tumacacori.

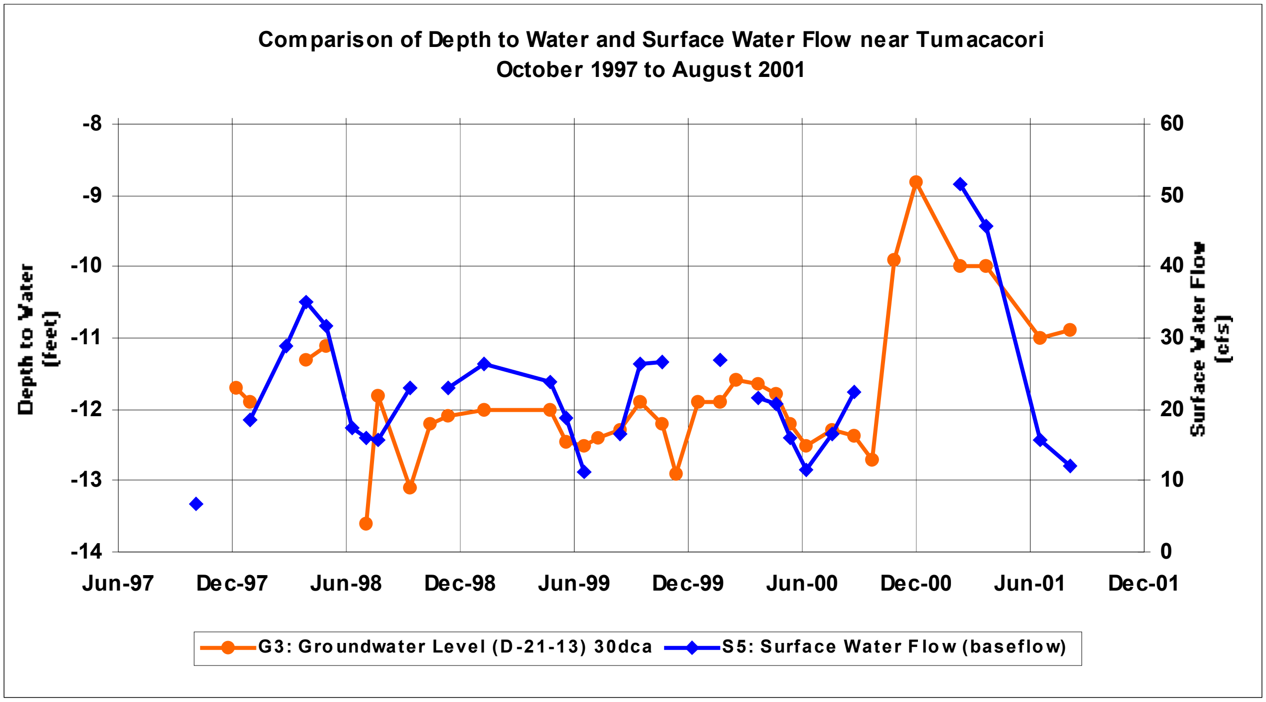


Figure 16. Comparison of depth to water and baseflow: Santa Cruz River effluent-dominated reach near Amado.

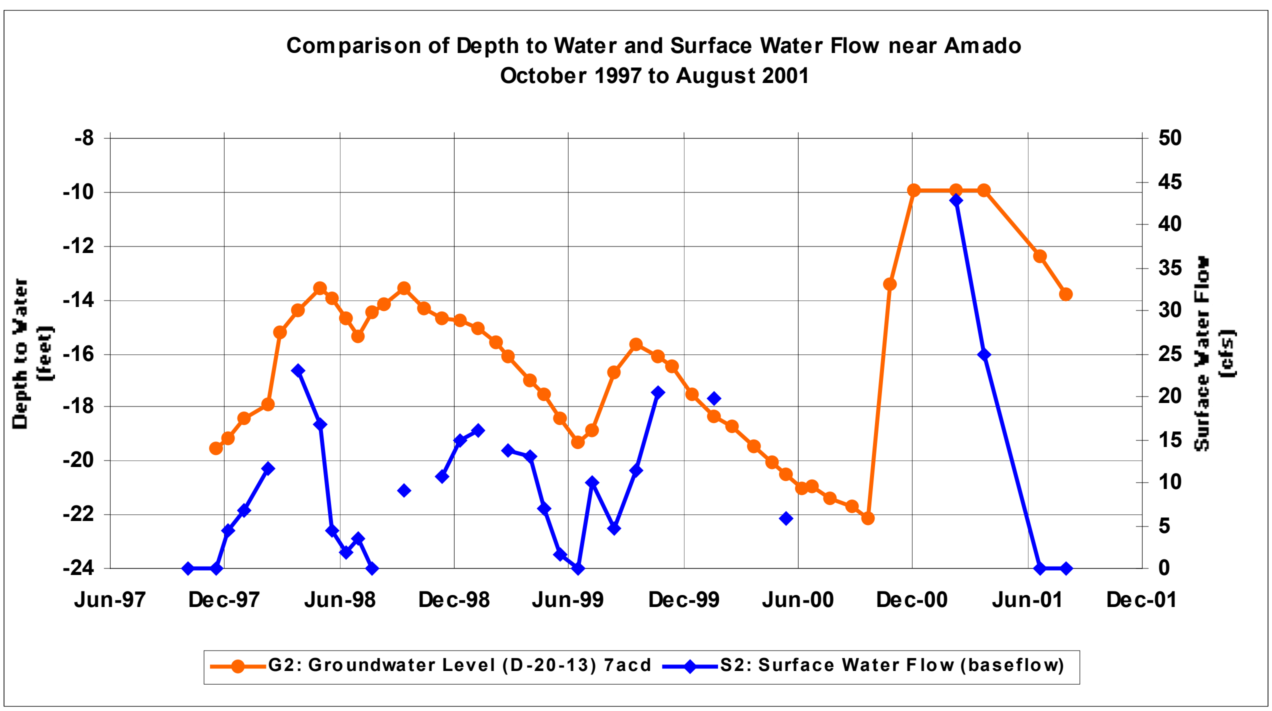


Figure 17. Comparison of depth to water and baseflow: Santa Cruz River effluent-dominated reach near Rio Rico.

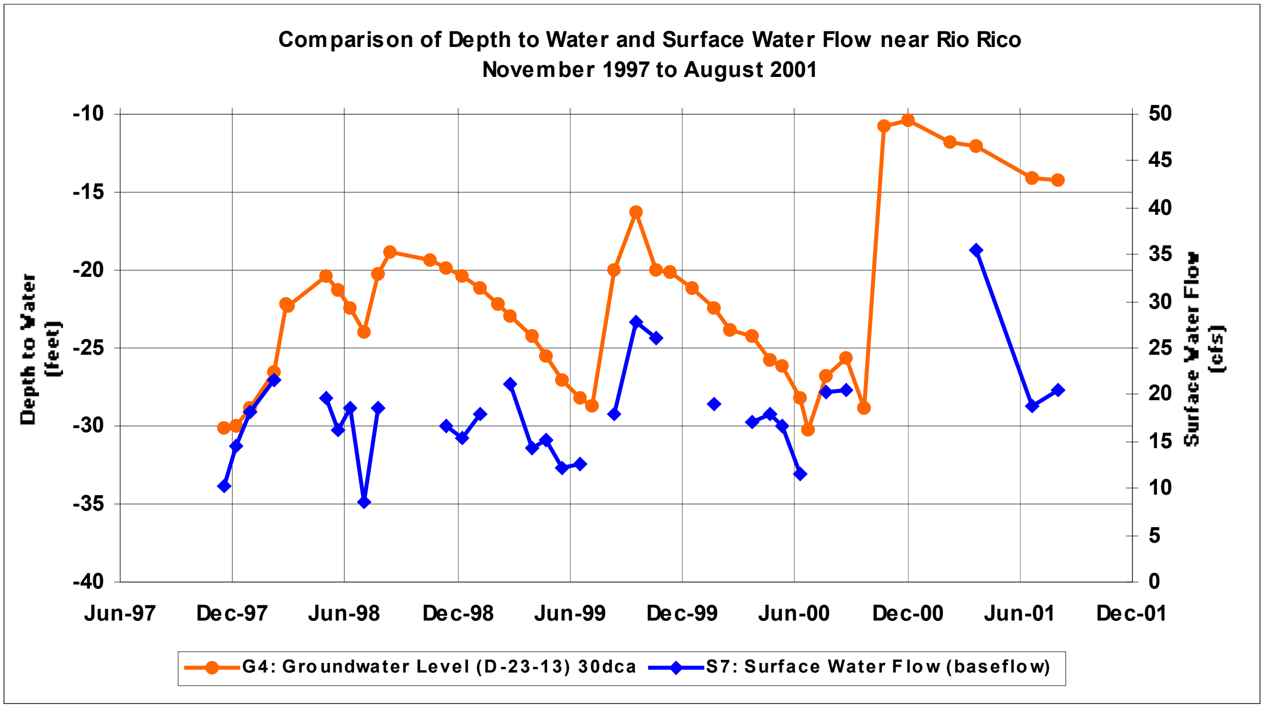


Figure 18. Tributary flow in Peck Canyon, November 2000.

Figure 19. Surface water flow in the effluent-dominated reach of the Santa Cruz River intermittent sections.

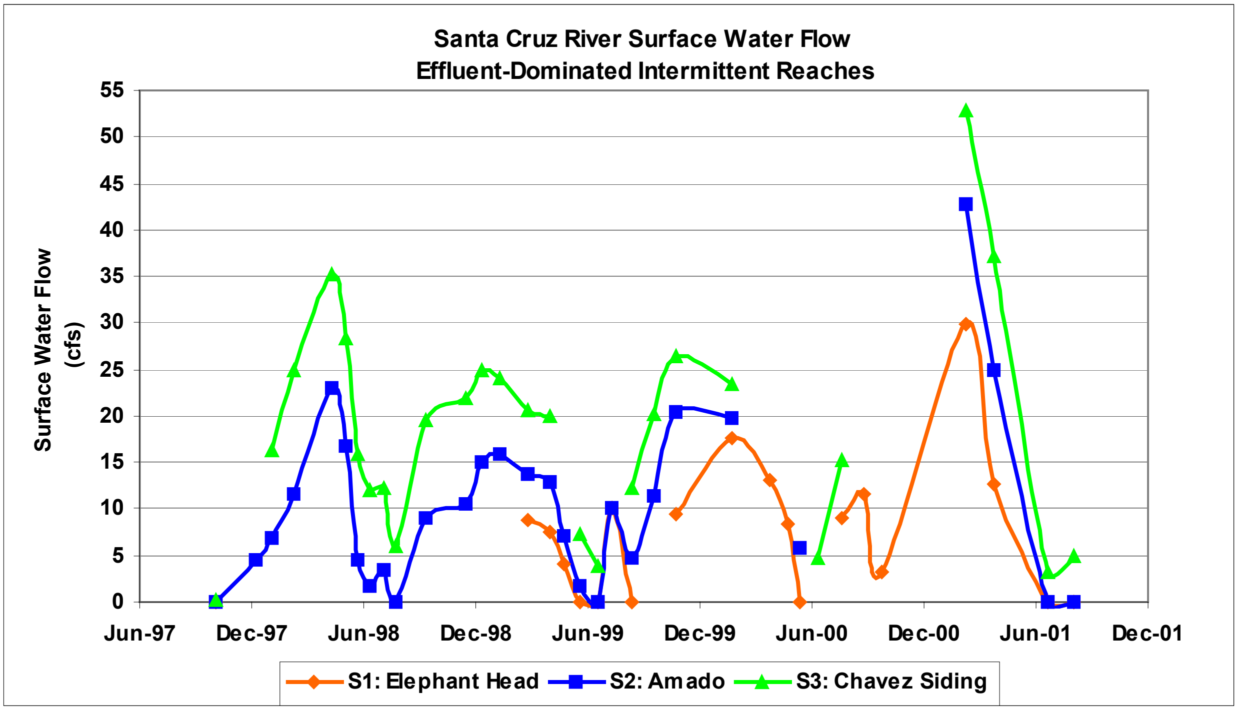
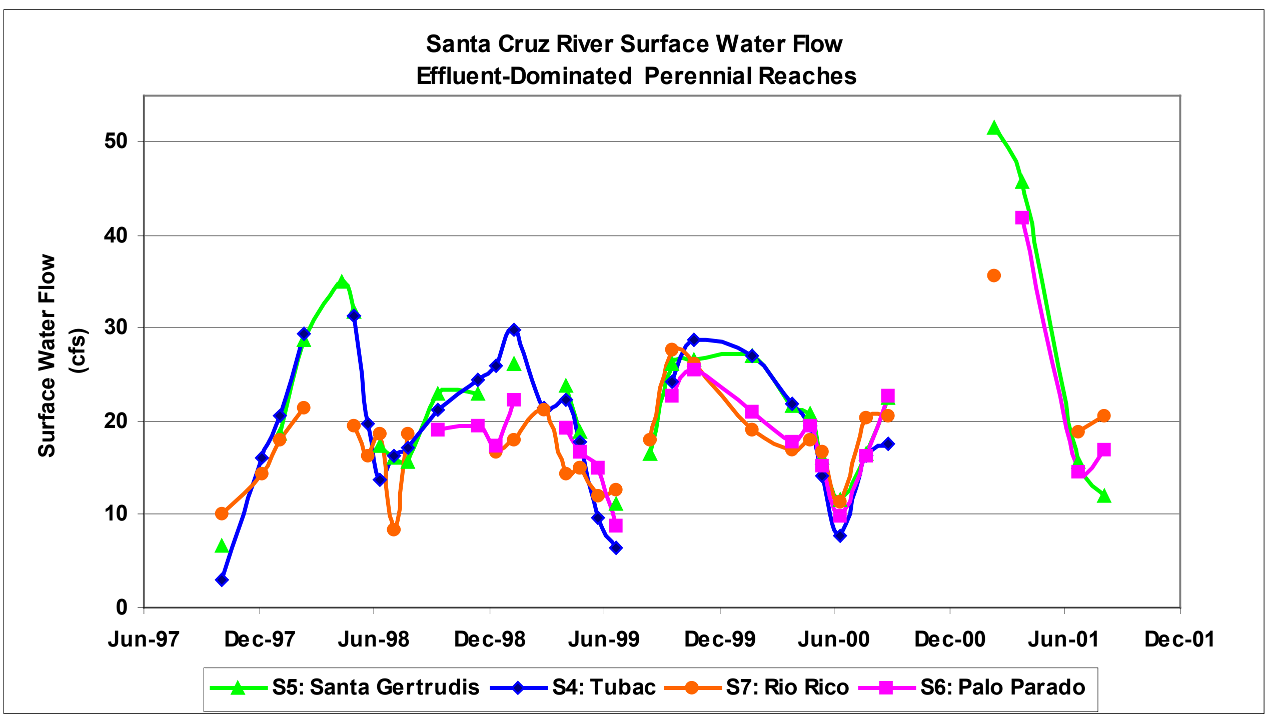


Figure 20. Surface water flow in the effluent-dominated portion of the perennial sections of the Santa Cruz River.



UNITED STATES GEOLOGICAL SURVEY SURFACE WATER DISCHARGE DATA

The United States Geological Survey currently operates two continuous-record streamflow gages in the Santa Cruz AMA. Surface water discharge data is collected and transmitted via satellite link to USGS offices allowing for the calculation of mean daily discharge. Real-time data can also be accessed from the USGS website.

Gage 09480500, Santa Cruz River near Nogales, is located approximately 0.8 miles north of the International Border. The drainage area is 533 square miles of which 348 square miles are in Sonora, Mexico. The remainder of the drainage area is in the San Raphael Valley in Arizona where the headwaters of the Santa Cruz River are located. The streamflow has been periodically gaged at this site since 1913 and continuously gaged since July 1935 (appendix A).

Table 8. Monthly mean daily discharge data (cfs)– gage 09480500, Santa Cruz River near Nogales.

Calendar Year	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***	***Annual Mean***
1997	0.4	0.0	4.2	0.0	0.0	0.0	.00	9.0	7.7	0.1	0.0	.4	1.8
1998	0.0	70.0	13.9	29.9	.5	0.0	11.2	12.5	0.0	0.0	0.0	0.0	11.1
1999	0.0	0.0	0.0	0.0	0.0	0.4	16.2	89.4	32.3	3.6	1.1	1.2	12.2
2000	1.3	1.7	1.1	0.9	0.0	0.4	2.4	23.2	0.1	339.4	166.0	36.6	
2001	29.1	21.9	14.2	38.3	1.3	0.5	0.6						
Monthly Mean Daily Discharge	40.2	33.3	24.0	7.6	1.8	1.3	39.9	85.4	25.7	23.4	8.5	34.2	

Monthly mean daily discharge is the long-term mean for the period of record: 1913, 1917-1919, 1931-1933, and 1935 – present.
Long-term mean monthly value reported on USGS website.
Data reported for period October 1, 2000 through July 31, 2001 are provisional.
Provisional data not included in monthly or annual mean.
Data rounded to the nearest .1 cfs.
The annual mean daily discharge multiplied by 724 gives the annual discharge in acre-feet per year.

Gage 09481740, Santa Cruz River at Tubac, is located .25 miles east of Tubac on the east bank of the river underneath the Bridge Street Bridge. The drainage area is 1,209 square miles. It is important to note that this gage is located approximately 11 miles downstream from the NIWTP and the daily baseflow passing through the gage largely reflects the volume of effluent discharged from the NIWTP. The river has been gaged continuously at this site since October of 1995 (appendix A).

Table 9. Monthly mean daily discharge data (cfs) – gage 09481740, Santa Cruz River at Tubac.

Calendar Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Annual Mean*
1997	24.3	27.9	16.9	8.73	3.17	.95	2.2	32.8	30.6	15.1	8.6	23.8	16.2
1998	28.3	67.8	45.4	46.3	20.7	12.6	62.8	46.7	27.1	18.0	19.1	21.3	34.5
1999	23.8	23.5	19.7	14.2	7.55	3.8	48.2	58.9	69.1	28.0	28.0	18.9	28.7
2000	23.6	25.0	24.8	20.1	10.0	22.4	23.4	29.0	19.2	456.6	364.4	96.7	
2001	68.5	48.8	45.5	76.2	27.00	9.3	14.1						
Monthly Mean Daily Discharge	24.8	33.9	25.9	20.4	9.2	8.7	30.7	37.9	32.2	16.3	19.2	21.1	

Monthly mean daily discharge is the long-term mean for the period of record: October 1995 –present.
Long-term mean monthly value reported on USGS website.
Data reported for the period September 2000 through July 2001 are provisional.
Provisional data not included in monthly or annual mean.
Data rounded to the nearest tenth of a cfs.
The annual mean daily discharge multiplied by 724 gives the annual discharge in acre-feet per year.

Other stream gages in the Santa Cruz AMA that are no longer operational include 09481500 Sonoita Creek near Patagonia (1930-1984), 09481000 Nogales Wash at Nogales (1932-1934). Peak flow data is available for 09481700 Calabasas Canyon near Nogales (1963-1978), and 19481750 Sopori Wash at Amado (1948-1978). Historical data are from the USGS. The International Boundary and Water Commission (IBWC) also operated a gage in Mexico at El Cajon (1954-1974) immediately upstream of the town of San Lazaro. Pima County has gaged peak flows in the Santa Cruz River at Elephant Head Bridge near Amado (1987-1999) for flood control purposes. Additionally, the Friends of the Santa Cruz, an environmentally concerned citizens group, conducted gaging and water quality sampling work.

Table 10. Streamflow statistics for USGS gages in Santa Cruz AMA.

Gage Description	*Gage Number*	*Mean Daily Discharge (cfs) 10/01/97 to 07/31/01*	*Median Daily Discharge (cfs) 10/01/97 to 07/31/01*	*Minimum Daily Discharge (cfs) 10/01/97 to 07/31/01*	*Maximum Daily Discharge (cfs) 10/01/97 to 07/31/01*	*Total Flow Volume by water year (AF)*	*Historical Median Flow Volume (AF) for period of continuous record by water year*
Santa Cruz River nr. Nogales	09480500	32.8	0.3	0.0	4700.0	1998 - 8,030 1999 - 8,440 2000 - 2,287	1936 - 2000 13,268
Santa Cruz River at Tubac	09481740	48.2	22.0	0.7	7090.0	1998 - 24,322 1999 - 19,750 2000 - 16,465	1996 - 2000 16,465

Stream gage data and graphics source USGS website: http://www.usgs.gov/nwis/

The data in table 10 are presented using two statistical parameters, the mean and the median. The mean of a set of streamflow measurements is the arithmetic average. It is important to note that the mean is influenced by the extremes in the data set and does not necessarily reflect "typical conditions". A record breaking wet event would tend to skew the data higher and would be reflected in mean or average value. The mean may not be what usually occurs in the data population. The median is the midpoint of the data set or the 50th percentile meaning one-half of the measurements are greater than the median and one-half of the measurements are less than the median. This value is particularly useful where extremes occur, as it is usually more representative of "typical conditions".

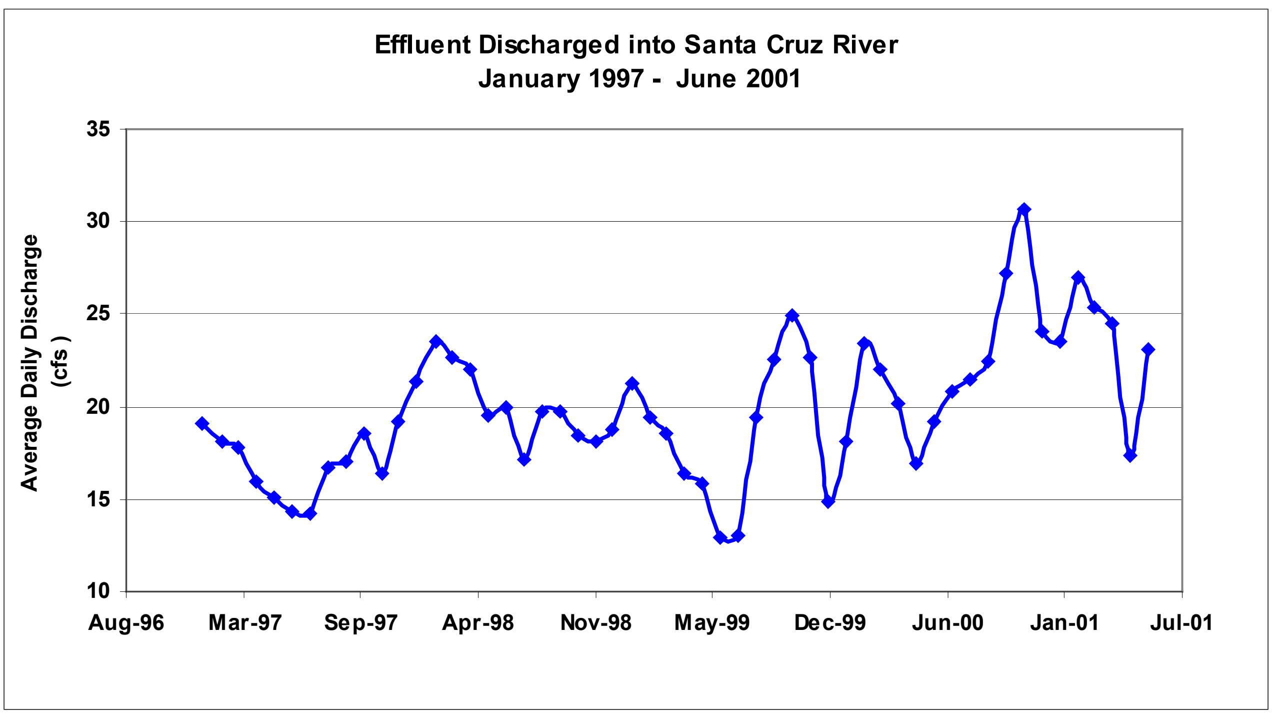
EFFLUENT DATA

The Nogales International Wastewater Treatment Plant treats sewage from Nogales, Arizona and Nogales, Sonora. The treated effluent is then discharged directly to the Santa Cruz River near the confluence of Nogales Wash and Sonoita Creek. The plant has been at its current location since December 18, 1971. It was previously located along the east bank of Nogales Wash approximately two miles north of the International Border. The discharges from the plant are integral to maintaining surface water flows in the river and recharging the aquifer downstream.

Table 11. Monthly discharges (acre-feet) from the NIWTP (January 1997 – June 2001).

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1997	1172	1006	1091	927	852	875	1029	1015	1015	1138	978	1179	12211
1998	1316	1305	1395	1310	1200	1189	1057	1211	1176	1131	1081	1155	14524
1999	1304	1078	1138	975	974	767	803	1194	1344	1531	1348	912	13367
2000	1115	1303	1357	1200	1402	1141	1280	1319	1338	1671	1824	1477	16066
2001	1450	1500	1560	1455	1065	1372							

Figure 21. NIWTP effluent discharged (January 1997 – June 2001).



Effluent data source: U.S. Section, International Boundary and Water Commission, Nogales International Wastewater Treatment Plant, direct communication, 2001

ESTIMATION OF SPECIFIC YIELD IN THE MICROBASINS AND GRAVITY SURVEYS

Specific yield, the percentage volume of water released from aquifer storage by draining a unit volume of saturated aquifer material, is a fundamental property of the aquifer system. Assessing the specific yield is an important task required to build the computer model. Specific yield estimates are usually developed from aquifer test data of the AMA's groundwater system. However, to supplement the sparse aquifer test data in the Santa Cruz AMA, the Santa Cruz AMA Groundwater Users Advisory Council (GUAC) approved funding for ADWR personnel to conduct relative gravity surveys in the Kino Springs and Highway 82 microbasins. Gravity surveys have been used in recent hydrologic studies to relate changes in mass to changes in groundwater storage and thus estimate specific yield. The USGS has been performing these types of surveys in the western United States over the last few years and have published several papers and water resources investigation reports documenting their results. For details of the general procedure see Pool and Eychaner (1995).

Gravity surveys were conducted at four well sites in the microbasins prior to, during and immediately after the 1999 monsoons. Estimates of specific yield based on changes in gravity measurements for the three sites located directly in the YAl ranged between 12 and 14.4 percent. Gravity data measured at one site located near the geologic contact between the YAl and OAl resulted in a specific yield of 8.6 percent. Although the results are preliminary, the gravity method seems to provide reasonable estimates for these types of units. Table 12 lists well sites and estimates of specific yield.

Table 12. Gravity survey results of specific yield.

Well Location	*Hydrogeologic Unit*	*Change in Groundwater Level (feet)*	*Change in Gravity (micro-gals)*	*Specific Yield (percent)*
G11: D-24-15 06aad	YAl	25.6	47	14.4
G9: D-23-15 31cac	YAl; approximately 200 feet away from OAl	28.5	44	12.1
G6: D-23-14 25cdb	YAl and OAl contact	39.2	43	8.6
G5: D-23-14 27add	YAl; approximately 200 feet away from bedrock.	22.8	35	12.0

In addition to the 1999 gravity survey, the Department and the Santa Cruz GUAC have funded two other geophysical studies in the AMA. One study conducted by Gettings and Houser (1996) combined geologic and geophysical methods to determine the shapes and locations of the sub-basins that make up the Upper Santa Cruz Basin. That study also described the sediments that fill the sub-basins and estimated the thickness of the lower basin fill relative to the upper basin fill. Another study, conducted by Hydrogeophysics, Inc. (2001) was a multi-method geophysical investigation to further define sub-basin geometry in the Potrero Canyon and Nogales Wash area as well as near the northern AMA boundary. Additional geophysical data regarding the microbasins can be found in *Geophysical and Geohydrological Investigation of Santa Cruz River Valley, Arizona, International Boundary to Mouth of Sonoita Creek* (Halpenny, 1963).

PRECIPITATION DATA

Monthly precipitation data are used to assess variations in climatic conditions. Comparisons between recent and long-term precipitation data are useful and aid in the interpretation of water level and surface water data. Precipitation data are also used in the evaluation and quantification of ungaged tributary flows and evapotranspiration rates.

Monthly total precipitation data for the years 1997 – 2000 were collected for the AMA at Nogales (025924) and Tumacacori (028865). Two other stations, which are no longer operational, Bear Valley (020665) and Amado (020204), were also included for spatial and historical perspective.

Table 13. Monthly total precipitation - Tumacacori National Monument Station ID 028865 (inches).

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***June***	***July***	***Aug***	***Sept***	***Oct***	***Nov***	***Dec***	***Total***
1997	1.38	1.25	0.12	0.44	1.10	0.00	2.32	6.05a	2.77	0.00b	0.51	3.18	19.12
1998	0.07	4.22	1.64	0.02	0.00	0.06	5.08	1.88	1.19a	1.37	0.17a	0.37	16.07
1999	0.00	0.00	0.22	1.24	0.00	0.58	4.18	2.91	0.79	0.00	0.00	0.00	9.92
2000	0.05	0.35	1.44b	0.00	0.00	3.20	1.21	3.39	0.83	7.33d	1.42x	0.01z	17.8
Long-term Mean 1948-2000	1.09	0.89	0.85	0.31	0.16	0.46	3.88	3.77	1.52	1.11	0.66	1.36	16.13

Period of record 1948 to present.

Table 14. Monthly total precipitation - Nogales 6N National Monument Station ID 025924 (inches).

Month	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***June***	***July***	***Aug***	***Sept***	***Oct***	***Nov***	***Dec***	***Total***
1997	0.44	0.66	0.40	0.5	0.32	0.01	1.14	5.53	1.16	0.16	0.90a	3.62	14.84
1998	0.15	2.47	1.45	0.07	0.00	0.00	5.23	5.78	1.37	0.34	0.47	0.65	17.98
1999	0.00	0.00	0.01	1.01	0.00	0.08	7.14	3.02	1.76	0.00	0.00	0.00	13.02
2000	0.00	0.40	0.85	0.00	0.00	5.66	1.85	6.39	0.51	8.80	1.36x	0.03z	24.46
Long-term Mean 1948-2000	1.16	0.90	0.92	0.36	0.24	0.50	4.46	4.2	1.59	1.42	0.67	1.49	17.46

Period of record 1952 to present.

a = one day missing, b = two days missing, c = three missing, …etc…, z = 26 or more missing. Individual months not used for annual or monthly statistics if five or more days are missing. Individual years not used for annual statistics if any month in that year has more than five days missing.

Table 15. Long-term mean precipitation - Bear Valley Station ID 020665 (inches).

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Total*
Long-term Mean 1943-1957	1.78	0.90	1.40	0.47	0.10	0.33	4.63	4.82	1.52	0.84	0.82	1.23	17.96

(Period of record 1943 to 1957)

Data source for Tumacacori, Nogales and Bear Valley precipitation gages downloaded from Arizona State Climatology Lab website:
http://geography.asu.edi/azclimate
http://www.wrcc.dri.edu/cgi-bin

Table 16. Long-term mean Precipitation - Amado Station ID 020204 (inches).

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Total*
Long-term Mean 1948-1976	1.09	0.89	2000	0.31	0.16	0.46	3.88	3.77	1.52	1.11	0.66	1.36	16.13

(Period of record 1948 to 1976)

Data source for Amado precipitation gage printed from Climatedata west_1, Volume 11.0, NCDC Summary of the Day, Hydrosphere, 2000.

WATER USE

Current and historical water use data have been included in this report to illustrate trends and relative demand. Water use data provide important information that is used to assess the ever-growing demand on the aquifer system. Groundwater pumpage data are used to compile hydrologic water budgets, and supply well-specific pumpage inputs to the groundwater flow model.

Annual groundwater pumpage totals are metered for each non-exempt well in the AMA. The well owners report pumpage to ADWR as required by the Groundwater Code. These data are tabulated by sector use in Table 17 for the period 1997 to 2000.

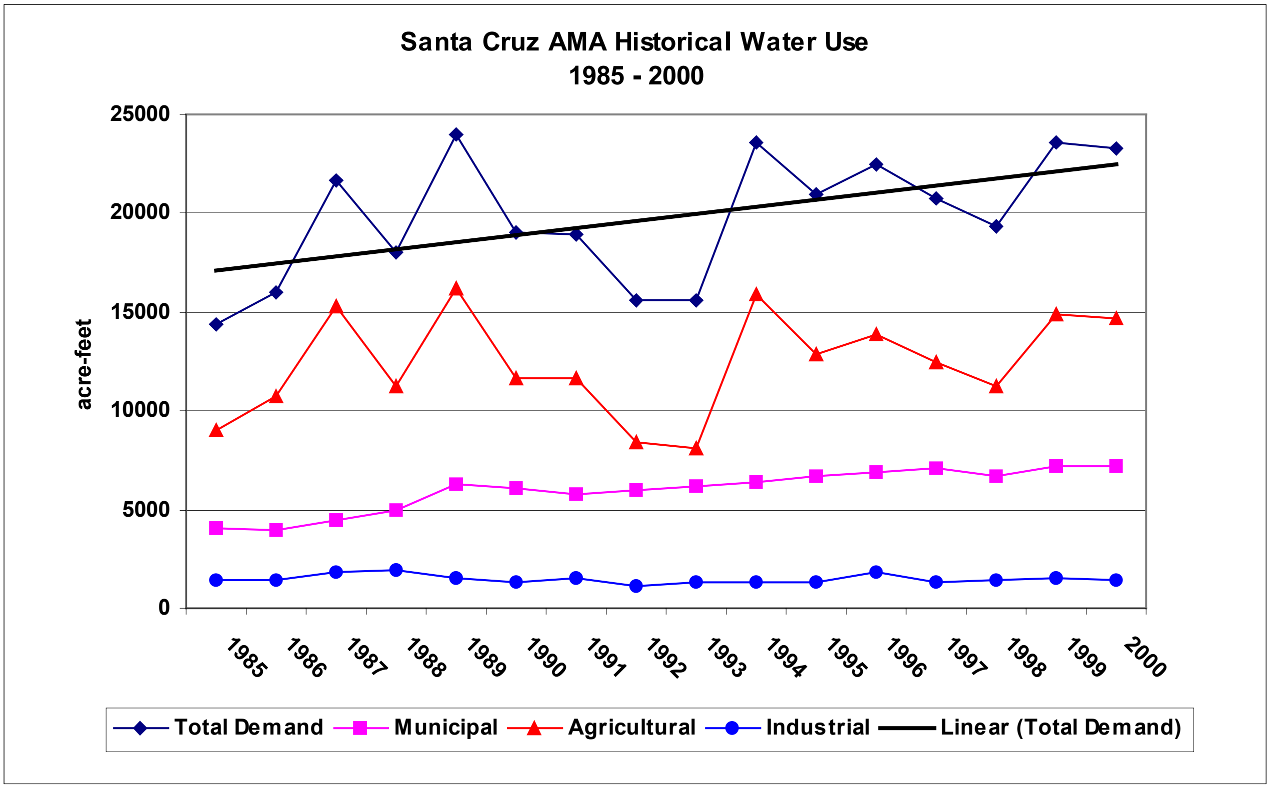
Riparian use has been estimated to be about 23,000 acre-feet per year and represents the single largest water use in the AMA (Masek, 1996, ADWR unpublished data). The estimate is based on 1992 aerial photography and field verification. The evapotranspiration rates were based on aerial photography, field estimates of density and species type, and published water use values for each species. Fremont Cottonwood and Gooddings Willow were grouped together as one vegetative type, which were then delineated into high, medium, and low density. The other major vegetative type, velvet mesquite, is similarly delineated into high, medium, and low density stands. Seasonal consumptive use estimates are generated by incorporating local climatological data into the Blaney-Criddle Formula. For this presentation, the values are not adjusted for effective precipitation. In other words, the amount of annual rainfall the plants would consume has not been subtracted from the total consumptive use estimates for each vegetative type. Riparian water use was also estimated for 1954 and 1973 from aerial photography.

Table 17. Reported non-exempt well pumpage in the Santa Cruz AMA 1997-2001 (acre-feet).

Year	***Municipal***	***Agricultural***	***Industrial***	***Total***
1997	7,043	12,326	1,145	20,514
1998	6,710	11,274	1,360	19,343
1999	7,193	14,898	1,443	23,534
2000	7,207	14,676	1,412	23,294

Source: ADWR Registry of Grandfathered Rights Database, 2001

Figure 22. Historic water use in Santa Cruz AMA 1985-2000.



WATER QUALITY

The Department's Basic Data Section gathers water quality samples from index wells on an annual basis. Some parameters are determined in the field however the majority of the parameters are determined in a laboratory analysis. The type and concentration of dissolved minerals can affect the usefulness of the groundwater for various purposes. The results of the three wells sampled indicate they are of suitable chemical water quality for most purposes. Table 18 lists the results of the most recent round of sampling that was conducted during the winter of 2000-2001. Historical laboratory analyses can be accessed at the USGS website http://water.usgs.gov/nwis/qwdata. Note the Department of Water Resources does not sample for organics or industrial pollutants.

In addition to the data collected by the Department, the Upper Santa Cruz Basin is a part of the National Water-Quality Assessment (NAWQA) program. The USGS and the Arizona Department of Environmental Quality are conducting the study. The goals of the program are to describe current water quality conditions for the Nation's freshwater streams, rivers, and aquifers; describe how water quality is changing over time; and understand the natural and human factors affecting water quality conditions. As a result many groundwater and surface water samples have been collected and analyzed. For more information on water quality in the Santa Cruz AMA contact the Arizona Department of Environmental Quality, the USGS and the University of Arizona (Scott, MacNish, and Maddock, 1996).

Table 18. Chemical constituents of groundwater in three select wells in Santa Cruz AMA.

Well location	D-19-13 29CBB2	D-22-13 34ADD unsurveyed	D-24-14 05ADB2[1]	NSDWR[2]
Date Measured	4/18/01	4/20/01	4/19/01	
Specific Conductance[3] μ/siemens	873	646	556	
Total Dissolved Solids[4] mg/l	584	401	350	500
Hardness[4] as CaO_3 mg/l	280	240	200	
PH[4]	7.5	7.5	7.3	6.5 - 8.5
Nitrate NO_3 dissolved as N mg/l	2.0	2.6	5.6	10.0[5]
Fluoride mg/l	.6	.4	.3	2.0
Sodium mg/l	80	43	33	
Calcium mg/l	91	76	62	
Magnesium mg/l	14	12	10	
Chloride mg/l	28	27	20	250
Alkalinity mg/l	230	230	193	
Sulfate mg/l	180	60	41	250

[1]Well located in Pima County but within SCAMA modeling area.
[2]NSDWR: National Secondary Drinking Water Regulations or secondary standards are non-enforceable guidelines regulating contaminants in drinking water. Blanks indicate no standard.
[3]Specific Conductance (@ 25 degrees Celsius) is an indicator of total dissolved solids.
[4]Total dissolved solids, Ph, and hardness were laboratory computed.
[5] Nitrate appears on the National Primary Drinking Water Regulation (NPDWR) list and is a legally enforceable standard that applies to public water systems.
Source: Basic Data Section, ADWR, 2001

SUMMARY

The Department has collected significant amounts of fundamental hydrologic data in the Upper Santa Cruz Sub-basin. Observation and assessment of surface water flow rates and groundwater level measurements over space and time reveal a complex hydrologic system. The hydrologic information collected will assist in the characterization of local and regional scale hydrology, as well as, provide calibration targets for hydrologic models currently being developed.

The Department will continue measuring groundwater levels (primarily in the YAl) and surface water flow, on a near-monthly basis, thus providing temporal continuity with existing data. In addition, the Department will continue to measure groundwater levels in the OAl on an annual basis and will expand groundwater measurements in areas currently experiencing growth.

Although surface water flow from many tributaries to the Santa Cruz River are intermittent or ephemeral in nature, efforts will be made to quantify, or estimate their contribution to the hydrologic system; these include the Nogales Wash, Sonoita Creek, Aqua Fria Canyon, Peck Canyon and Josephine Canyon. In addition, the Department will continue to explore the possibilities of using additional methods such as geophysical surveys, stable isotopic analysis of groundwater and surface water samples, exploratory well drilling and aquifer testing to assist in the characterization of hydrogeologic systems.

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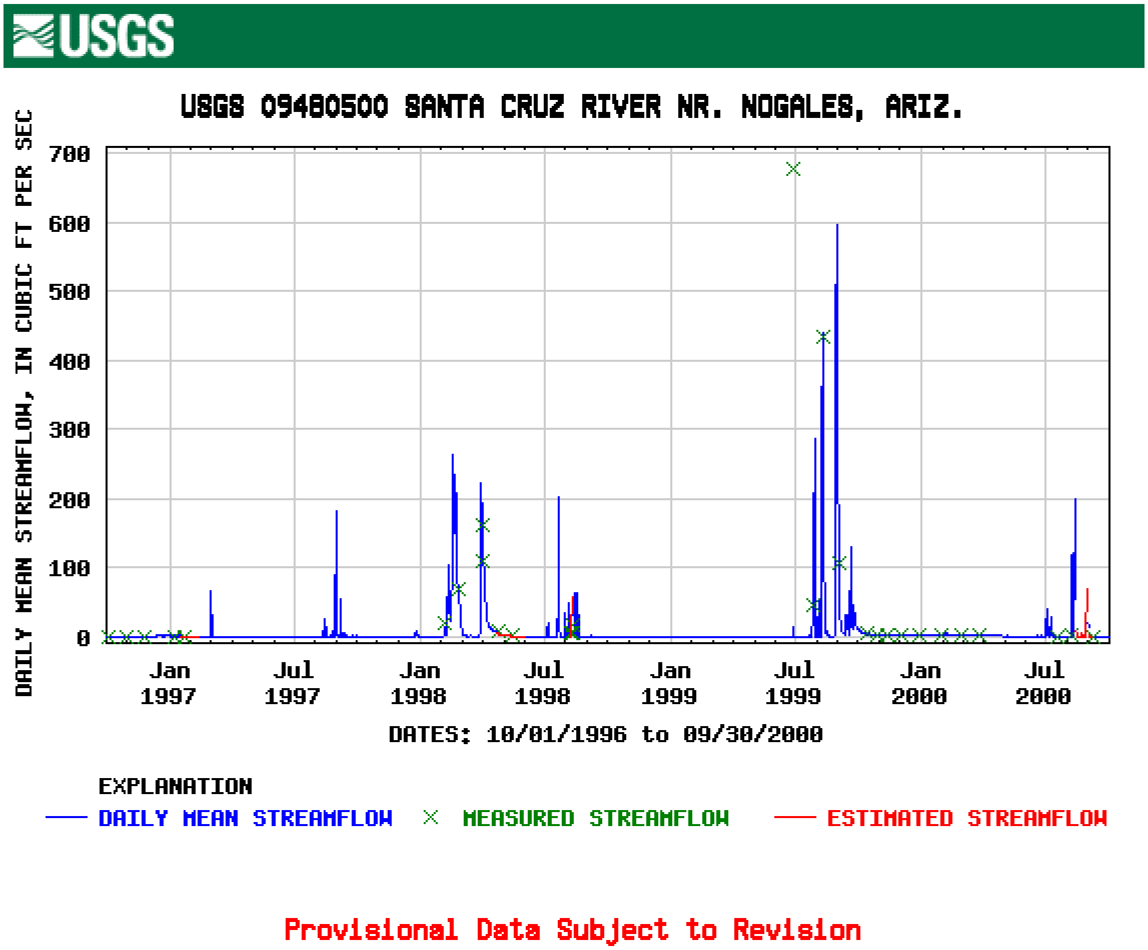
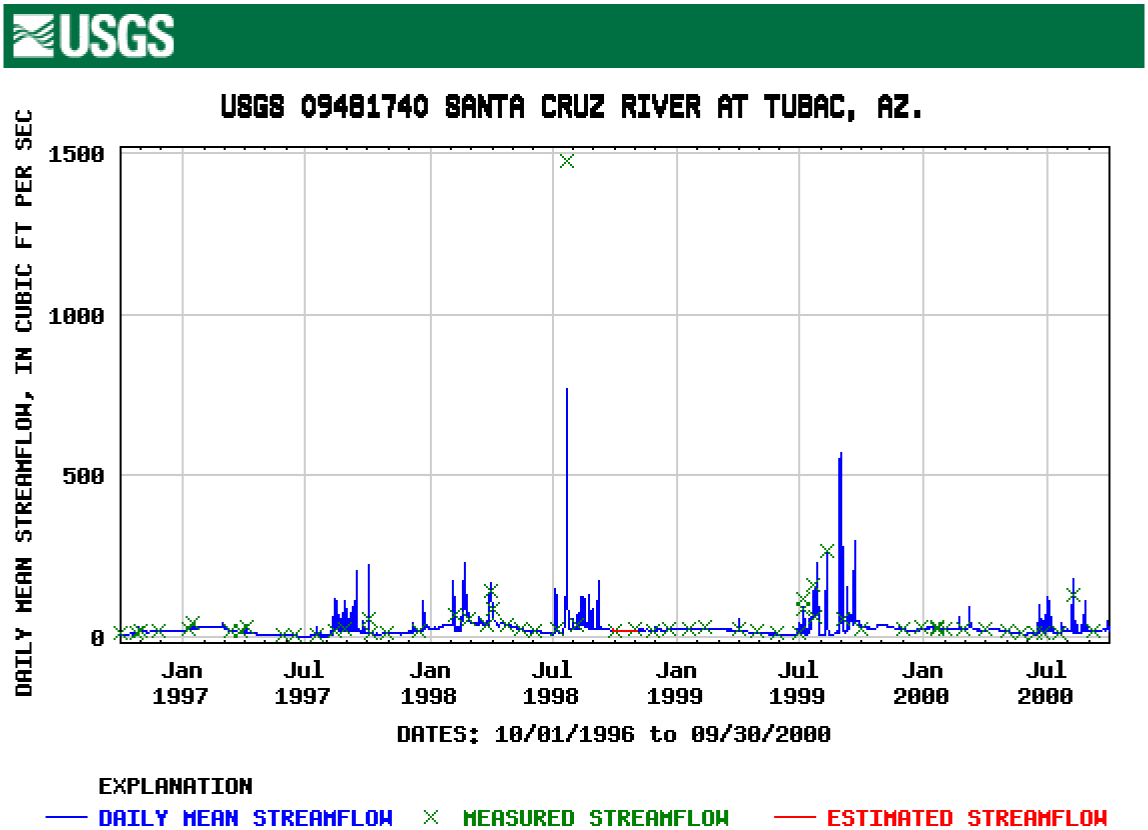
USGS gage data and graphics: http://www.usgs.gov/nwis/sw

EPA Drinking water standards: http://www.epa.gov/safewater/mcl.html

APPENDIX A - Daily Mean Streamflow Graphs


USGS
USGS 09480500 SANTA CRUZ RIVER NR. NOGALES, ARIZ.
DAILY MEAN STREAMFLOW, IN CUBIC FT PER SEC
700
600
500
400
300
200
100
0
Jan 1997
Jul 1997
Jan 1998
Jul 1998
Jan 1999
Jul 1999
Jan 2000
Jul 2000
DATES: 10/01/1996 to 09/30/2000
EXPLANATION
DAILY MEAN STREAMFLOW
MEASURED STREAMFLOW
ESTIMATED STREAMFLOW
Provisional Data Subject to Revision



Provisional Data Subject to Revision